LEO Download Capacity Analysis for a Network of Adaptive Array Ground Stations

Dr. Mary Ann Ingram

School of Elect. and Comp. Eng, Georgia Institute of Technology

June 28, 2005

Co-Authors:

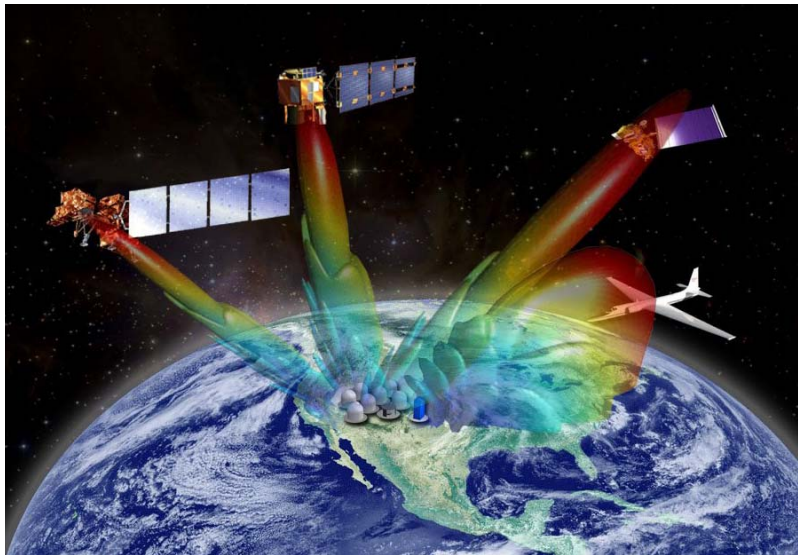
Mr. William Barott and Dr. Paul Steffes – GaTech;

Drs. Zoya Popović and Sébastien Rondineau – Univ. Col,

Dr. John Langley – Saquish Grp.;

Drs. Robert Romanofsky, Richard Lee, and Felix Miranda – GRC;

Mr. Dan Mandl – GSFC



Smart Antenna Research Laboratory

Georgia Institute of Technology

GRC GLENN RESEARCH CENTER at Lewis Field

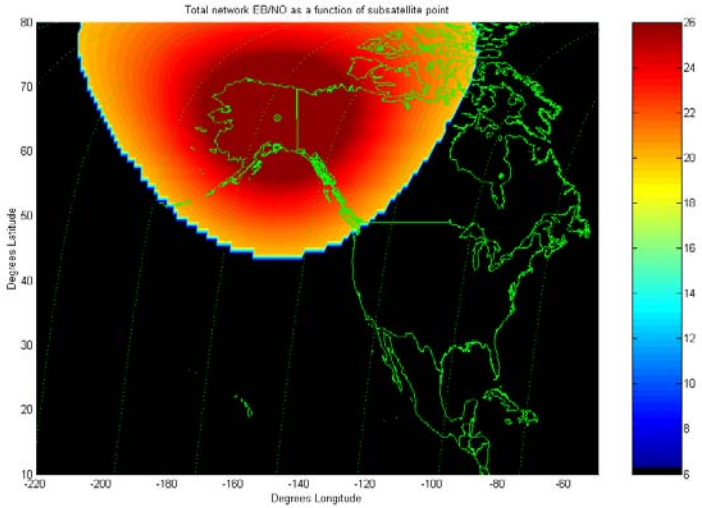
Goddard Space Flight Center

Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Reflectarray*
  - *Space-fed lens*
  - *Inflatable Array*
- *Network Capacity Analysis*
- *Conclusion*

The Current Technology

Large dishes in Poker Flats Alaska, Svalbord, Norway, and McMurdo Station, Antartica, each track one satellite at a time

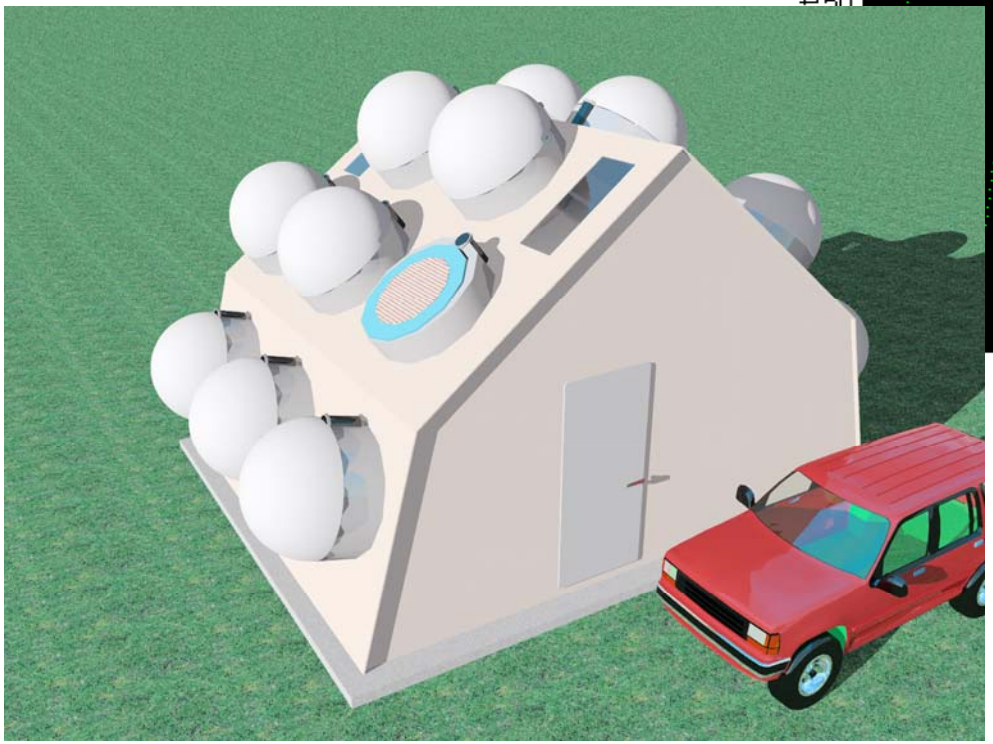


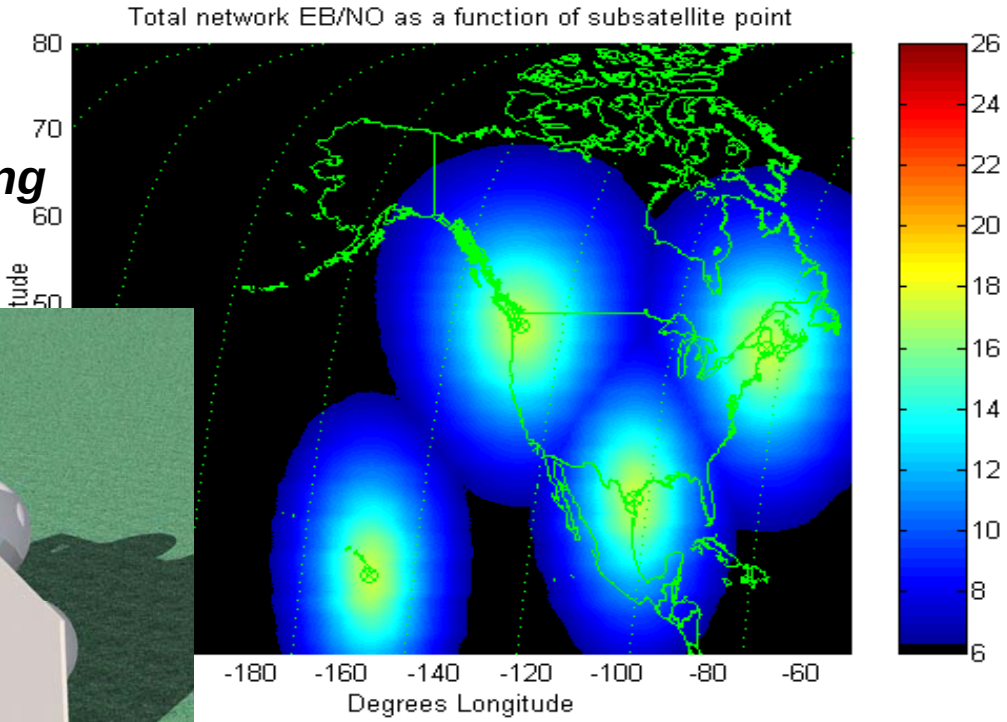
Limited Coverage Area

Harsh Environment
Costly Maintenance

The Vision for a New Ground Network

Low-cost ground stations at different locations around the world, each adaptively combining multiple phased arrays





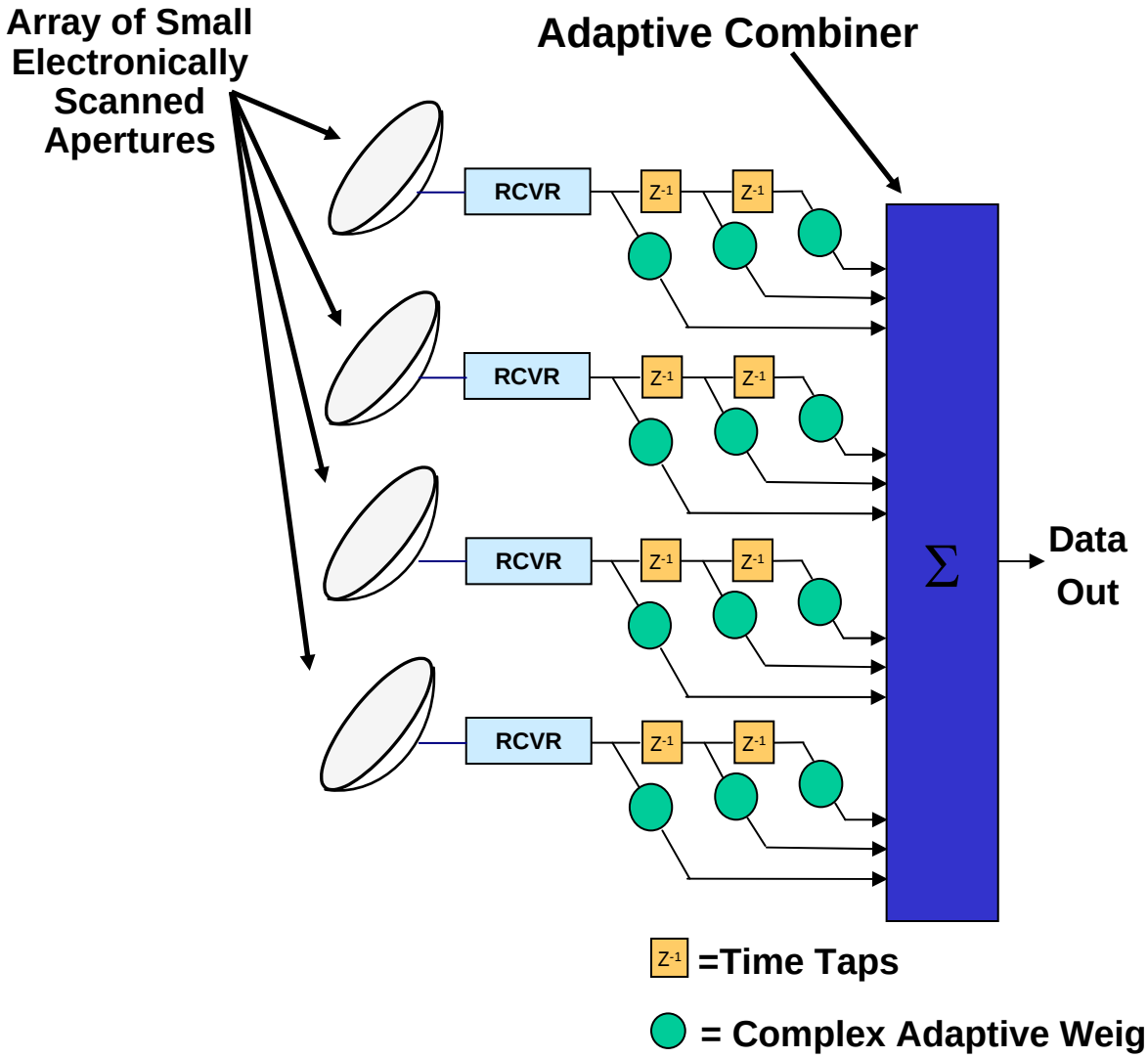
Minimal or no moving parts

Can locate in temperate zones

Graceful degradation

Multi-satellite tracking

Space-time Adaptive Processing (STAP)



Key Features

- ***Adaptive Combiner computes complex weights to provide best BER at output***
- ***Inexpensive Electronically Scanned Array elements***
- ***Multi-Satellite tracking***
- ***Exploits Multi-Path to enhance performance***
- ***Adaptation algorithms can null interfering signals***

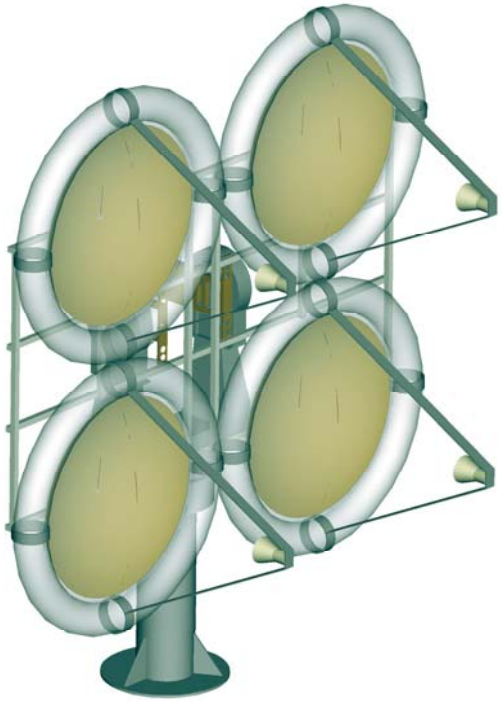
Demonstrations at Georgia Tech for SAC-C Satellite (6 Mbps @ X-band)

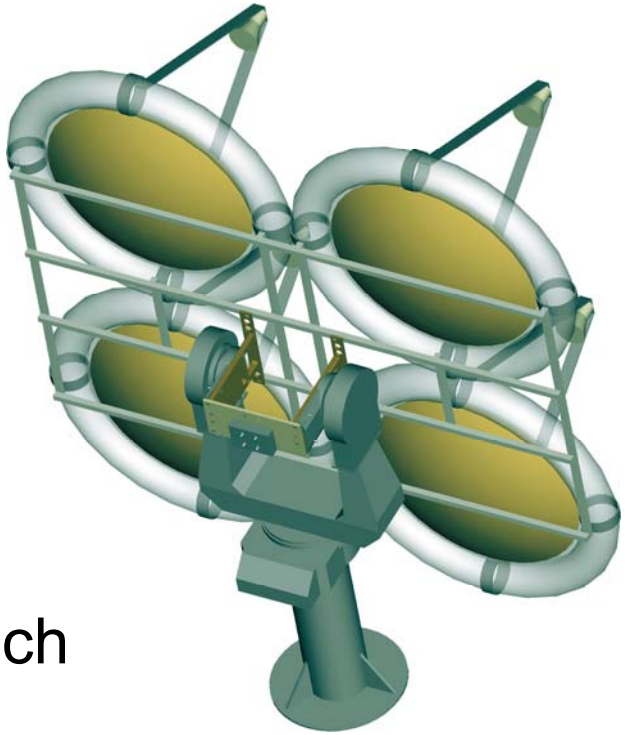
- *This summer, with four inflatable dish antennas and full mechanical steering*
- *This winter, with four space-fed lenses being developed at University of Colorado*

Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Inflatable Dishes*
  - *Space-fed lens*
  - *Reflectarray*
- *Network Capacity Analysis*
- *Conclusion*

Four Element Inflatable Reflector Array

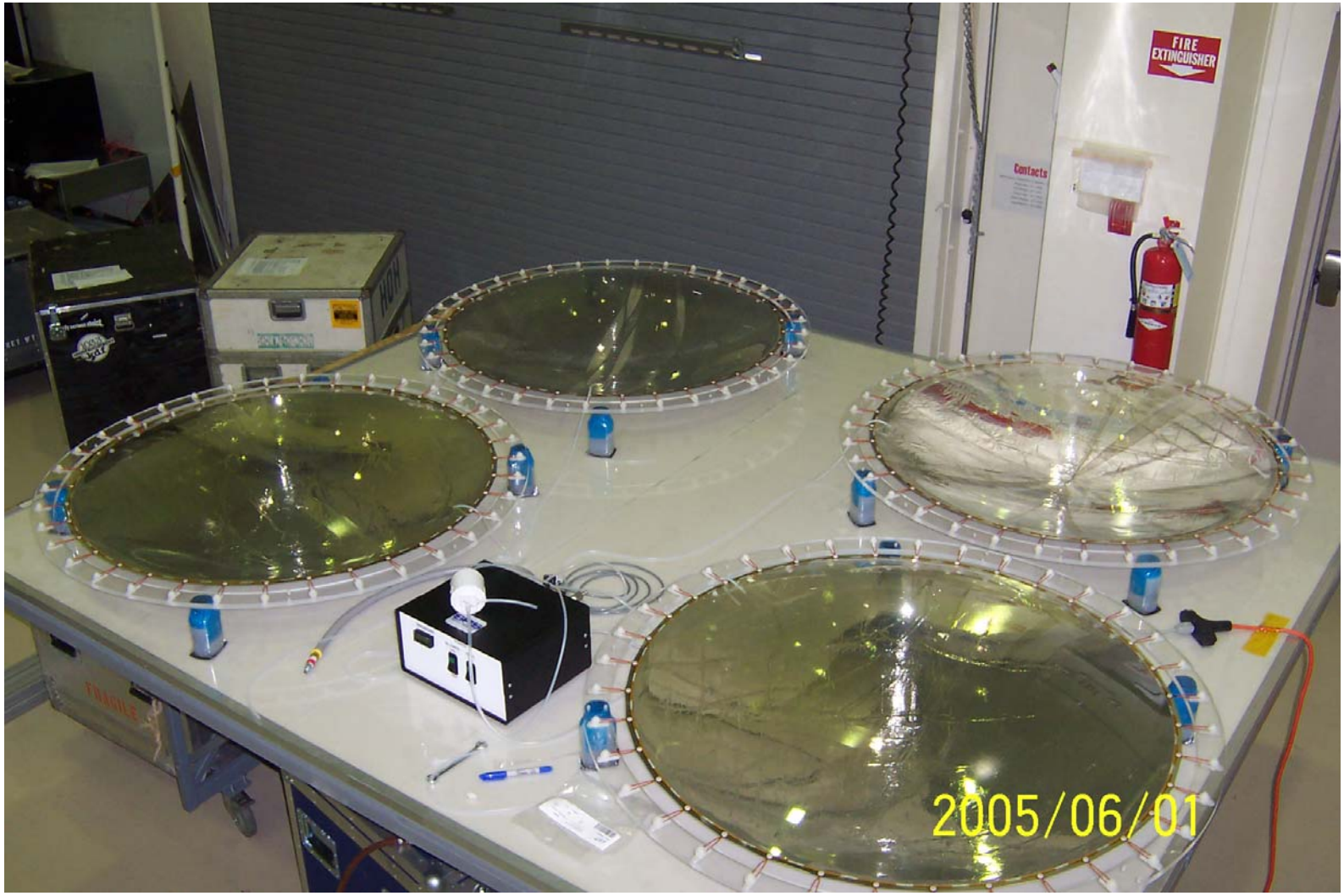




Expected Delivery to Ga Tech

August 1, 2005

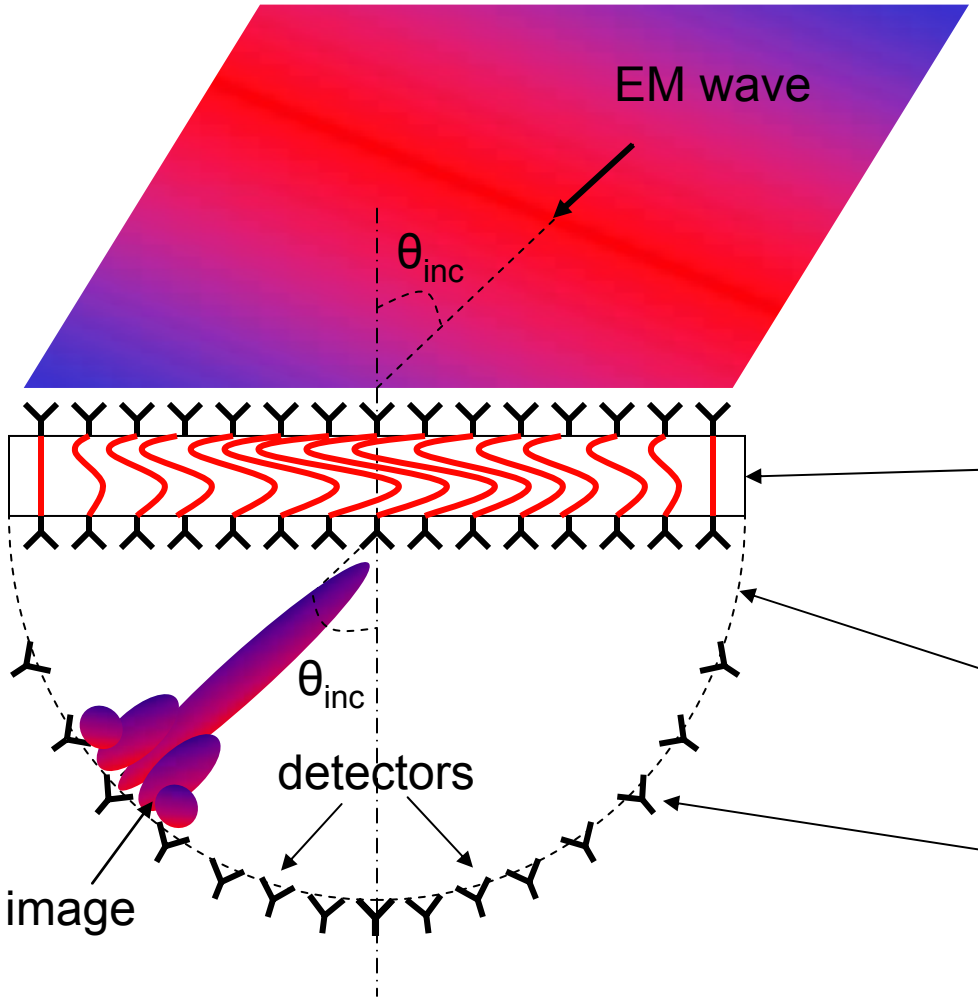
Films for the Inflatable Dish Antennas



Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Inflatable Array*
  - *Space-fed lens*
  - *Reflectarray*
- *Network Capacity Analysis*
- *Conclusion*

The Space-fed Lens (SFL)

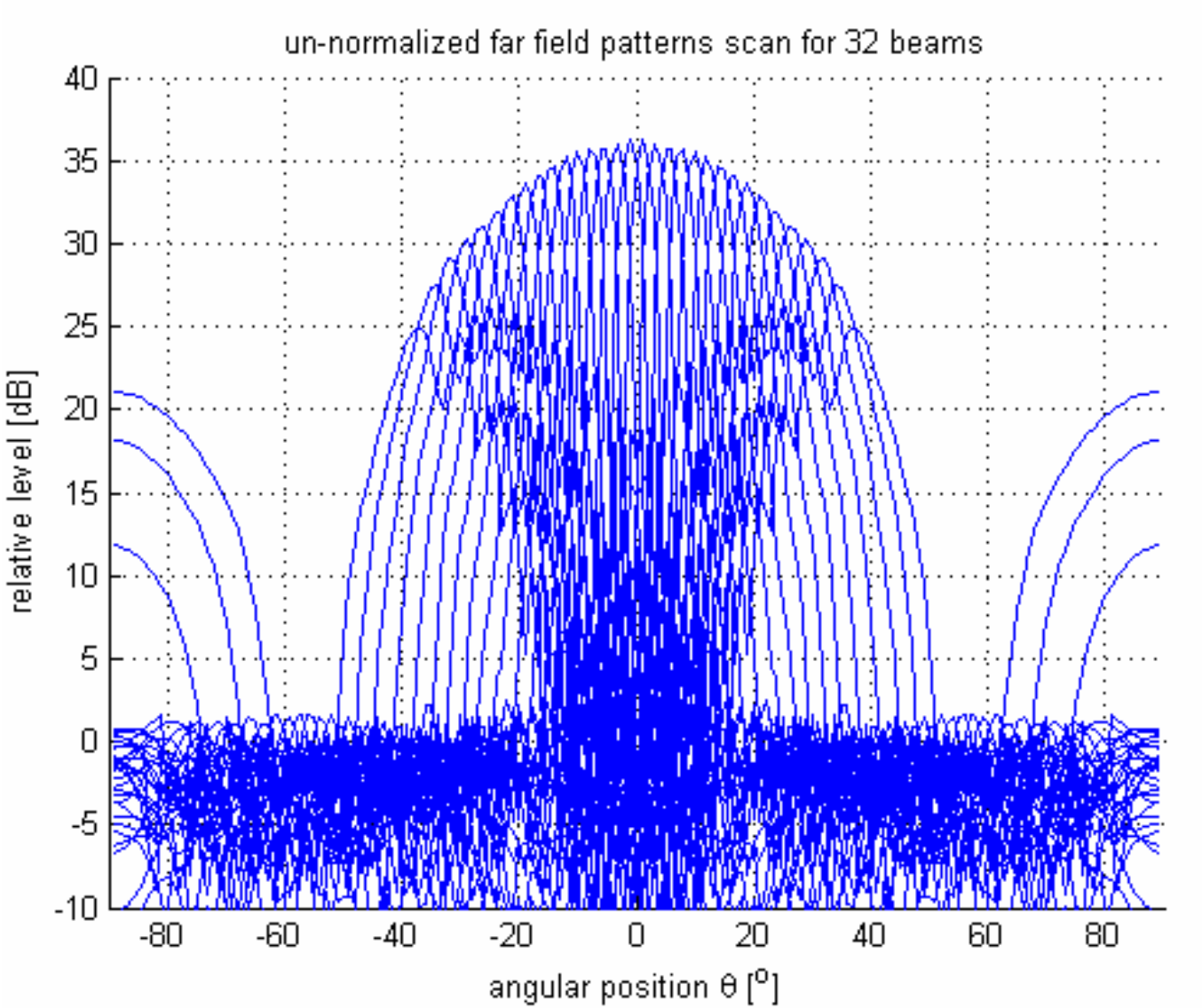


Lens made of inexpensive printed circuit board technology

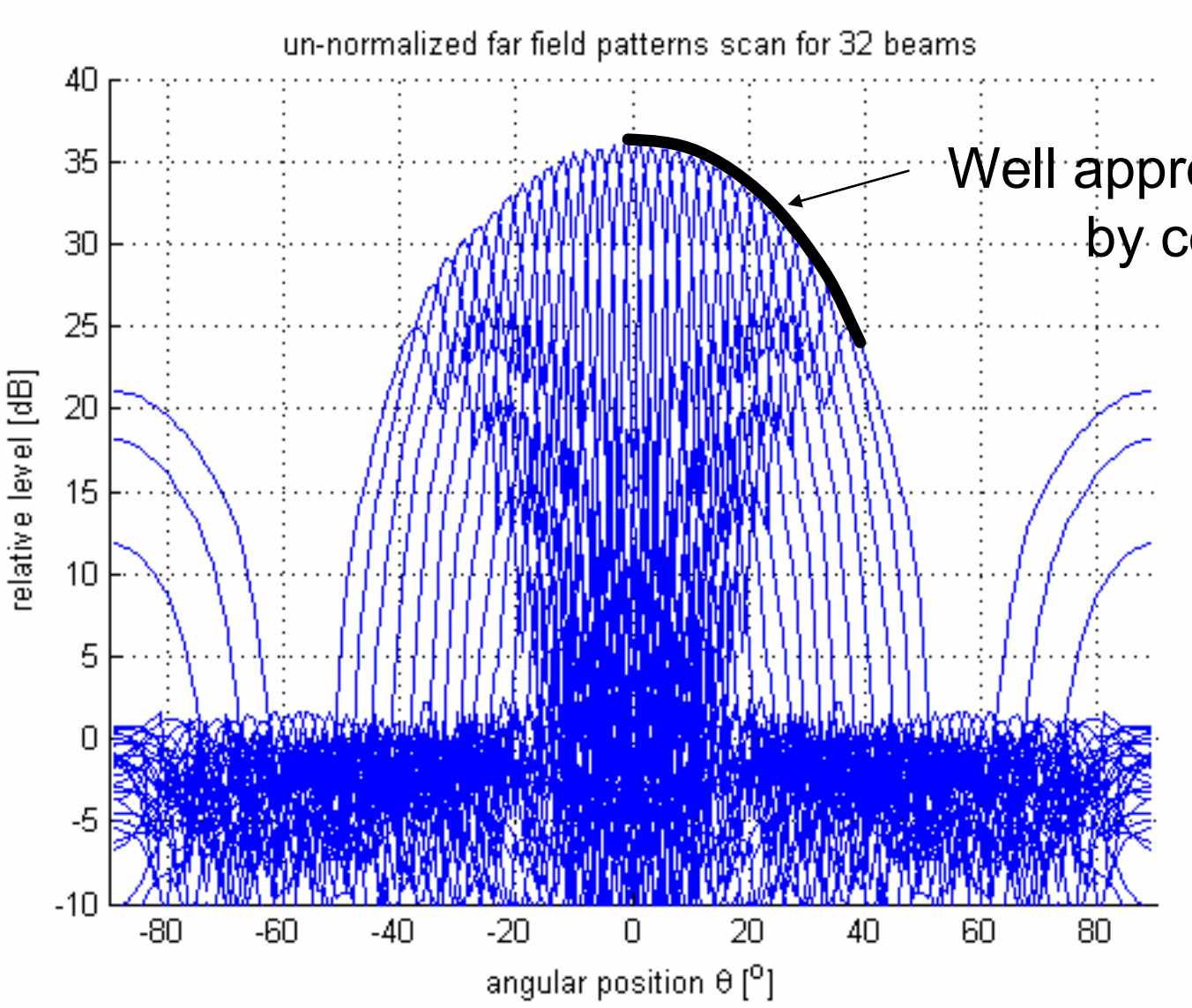
Focal surface

Feed elements – one per beam

SFL Beam Radiation Patterns for 32 Feed Elements

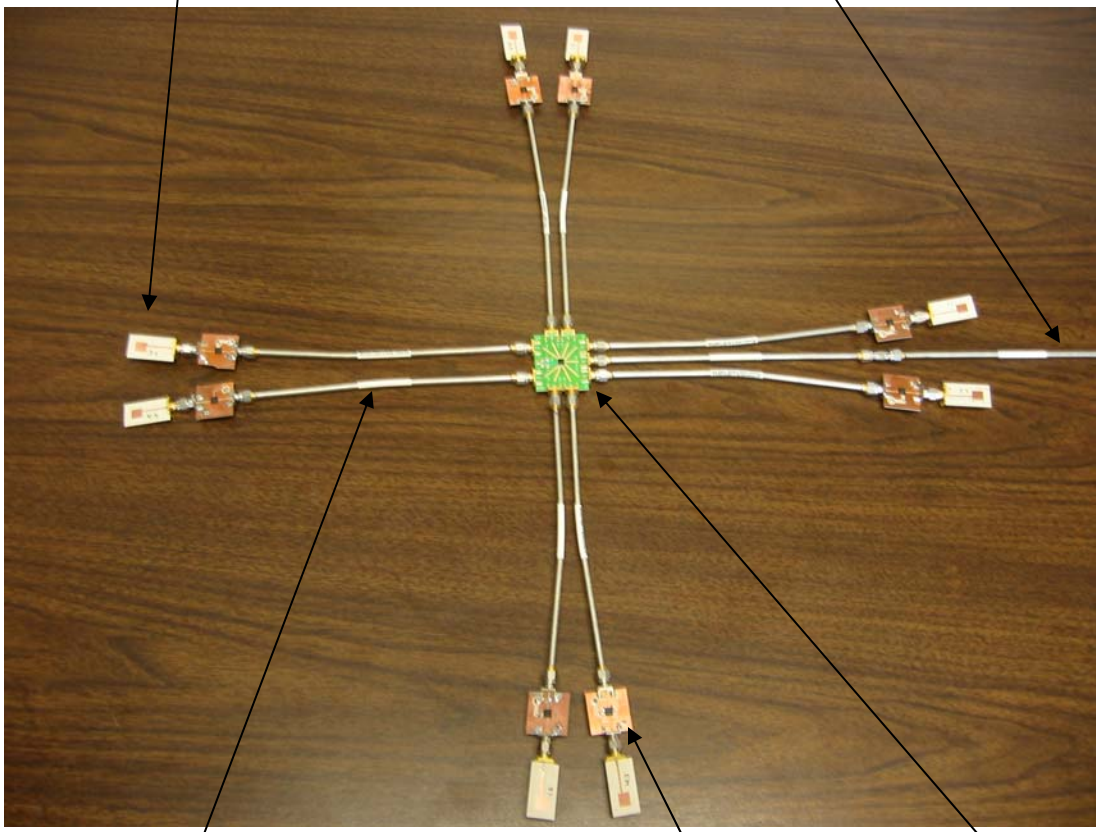


Scanning Loss – Loss in Peak Gain as Beam Steers Away from Broadside



SFL Intregration Schedule

¼ of the feeding network:



Bias lines are not added for picture clarity.

SFL delivery to U of Col.:
July 28th

SFL-feeding network mounting:
Beginning of August

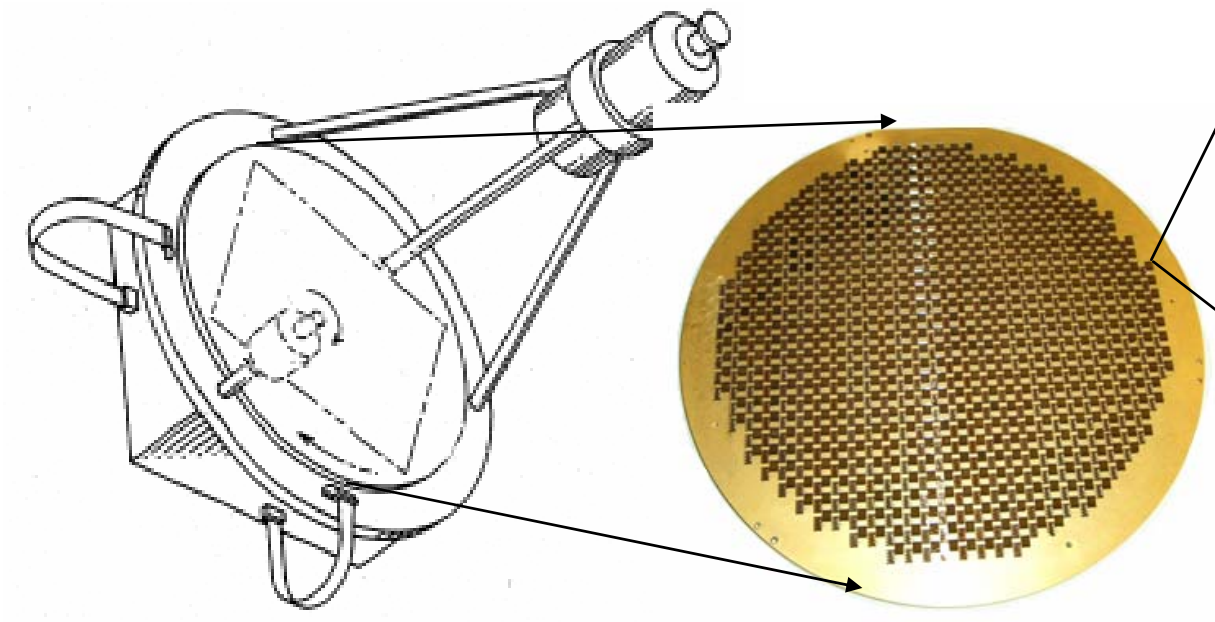
Integrated SFL testing:
Middle of August. Measurements will be done at NASA GRC.

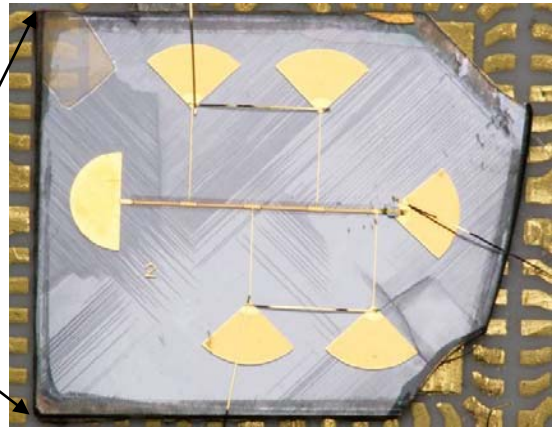
Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Inflatable Array*
  - *Space-fed lens*
  - *Reflectarray*
- *Network Capacity Analysis*
- *Conclusion*

Ferroelectric Reflectarray

- *Uses thin film ferroelectric phase shifters for elevation control and a stepper motor for azimuth beam steering*
- *Elevation-only electronic steering reduces phase shifter count from N^2 to N, where N is the number of radiating elements*
- *Very cost effective due to integration simplicity, reduced phase shifter cost, and radiators can be fabricated on "soft" substrates*





A prototype X-band phase shifter with 4 coupled microstripline sections and Si diode switch, which produced ≈310° of phase shift with 2.5 dB insertion loss.

Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Inflatable Array*
  - *Space-fed lens*
  - *Reflectarray*
- *Network Capacity Analysis*
- *Conclusion*

Network Capacity Analysis

- *Relates download capacity of the network to ground station design parameters*
  - *Number of ground stations*
  - *Number of antennas per ground station*
  - *Data rate*
  - *Dish vs. Hybrid electronic/mechanical scan*

Capacity Metrics

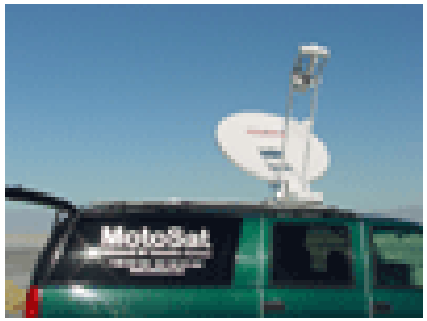
- *Average per day capacity in bits*
- *Assumes transmission happens only when link SNR > 6.38dB*
- *Average per pass based on 1^{o} intervals multiplied by 14.68 passes/day*

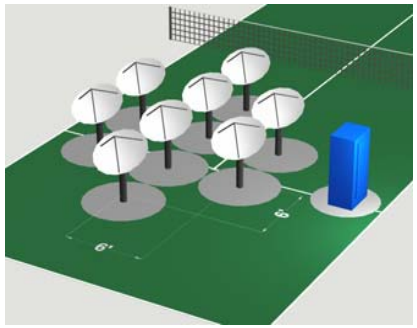
Cases Studied for EO-1 X-band (105 Mbps)

1. *11 m dish at Poker Flats, Alaska*
2. *Ground stations comprising multiple 0.75m dishes*
3. *Ground stations comprising space fed lenses*

CASE 2: Ground Stations with Multiple Dishes

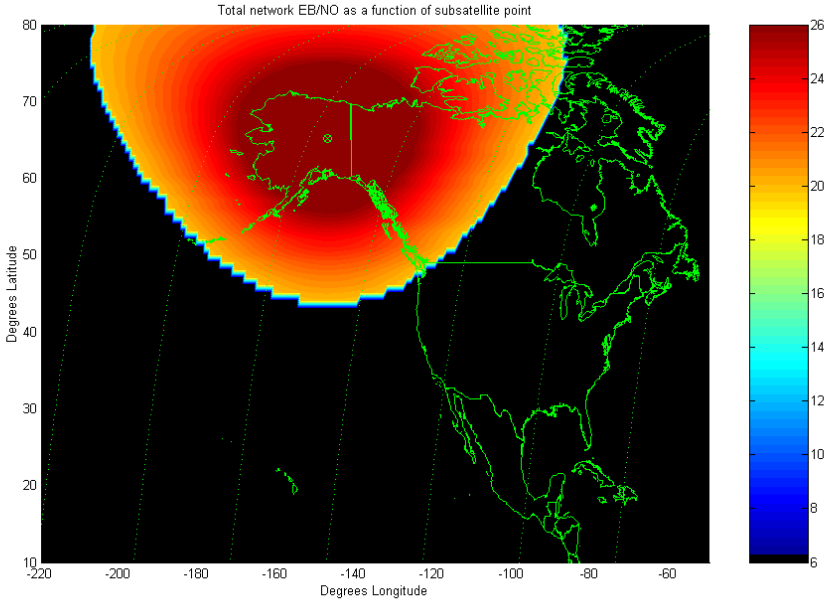
- *Based on Motosat 0.75m*
- *Perfect steering, perfect polarization matching*
- *Path loss, 6.5 dB implementation loss (from RFICD for EO-1); no fading*
- *Ground station T=150K*



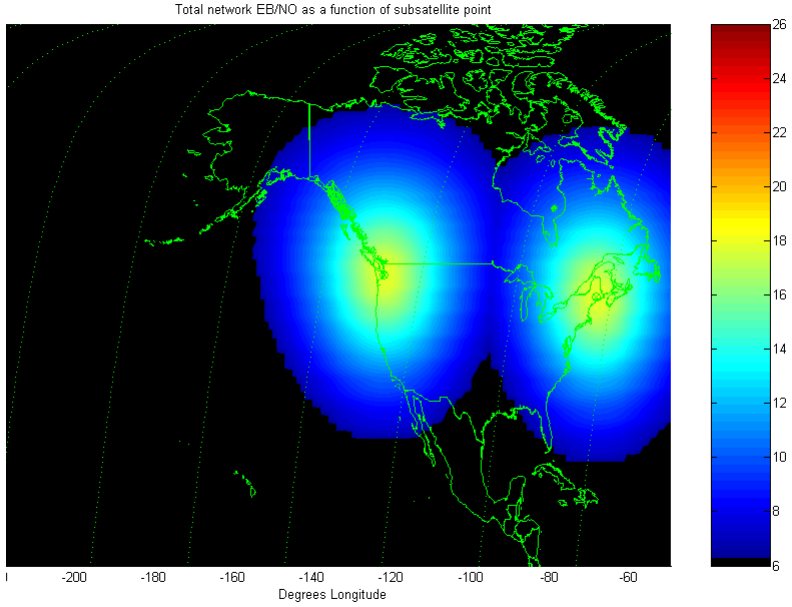


Energy per Bit per Noise Spectral Density (E_b/N_o) Contours

Case 1:11-meter Dish Poker Flats, Alaska: 105Mbps 585Gb/day



Case 2: 7 Dishes/Station Seattle, Bangor: 105Mbps 587Gb/day



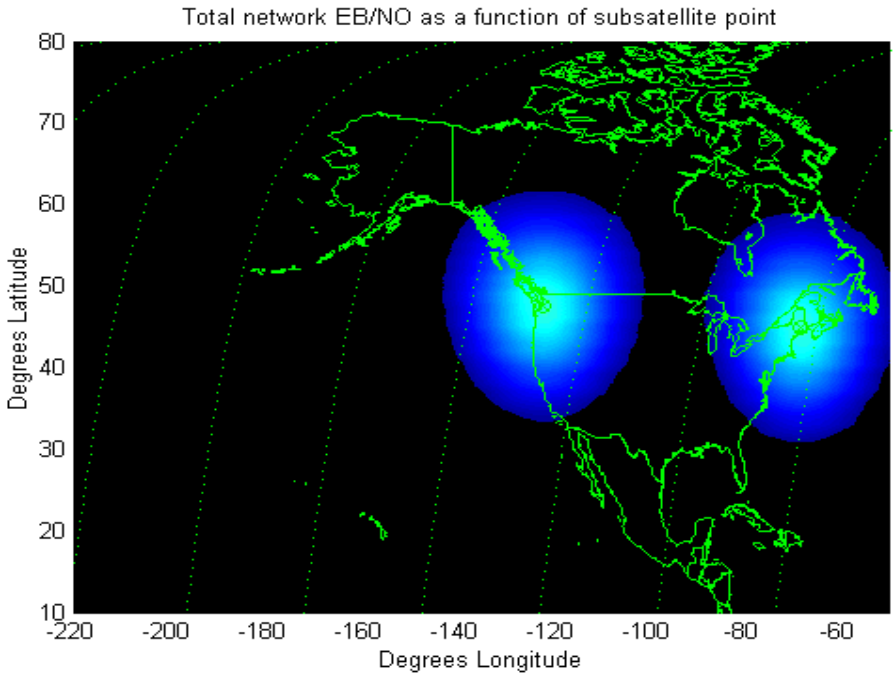
Summary of 105 Mbps Results for Cases 1 and 2

TX rate (Mbps)	Network	Total Number of Dishes	Avg Daily Capacity (Gb)
105	11m Poker Flats (PF)	1	585
105	5 el X3	15	545
105	5 el X2, 6 el X1	16	578
105	7 el X2	14	587
105	3 el X4	12	427

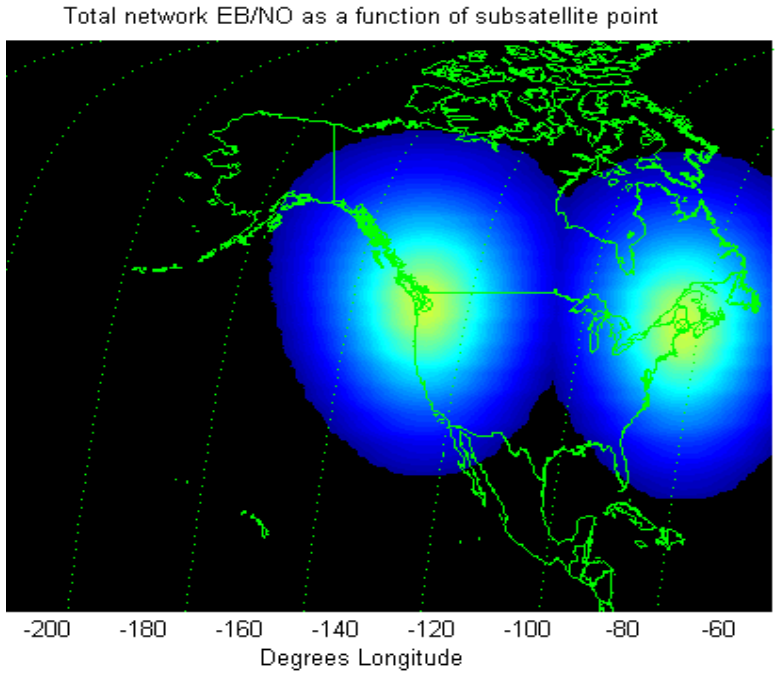
Fewer stations with more elements gives highest capacity, because they have lowest elevation coverage

Different Data Rates With 3 Dishes Each at Seattle, Bangor

105 Mbps 246 Gb/day



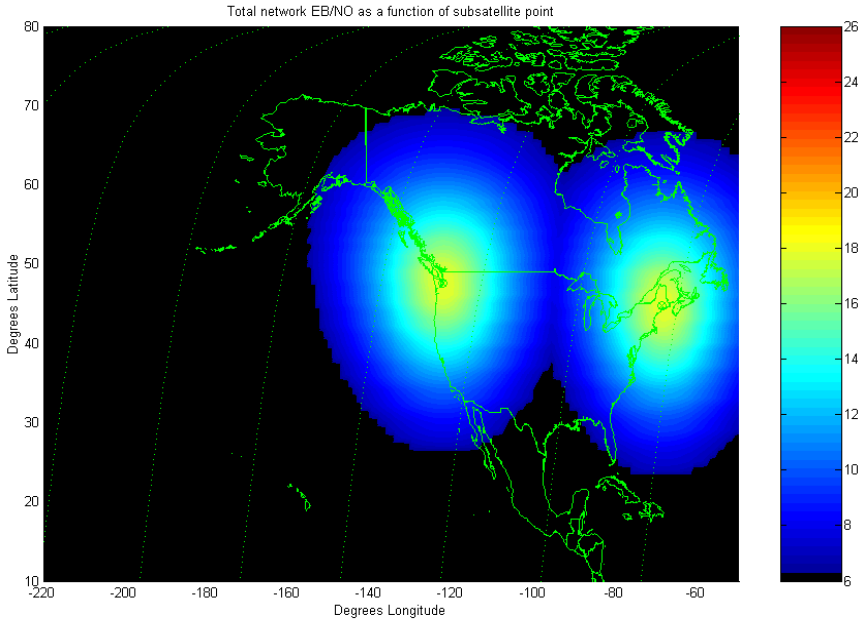
50 Mbps 270 Gb/day



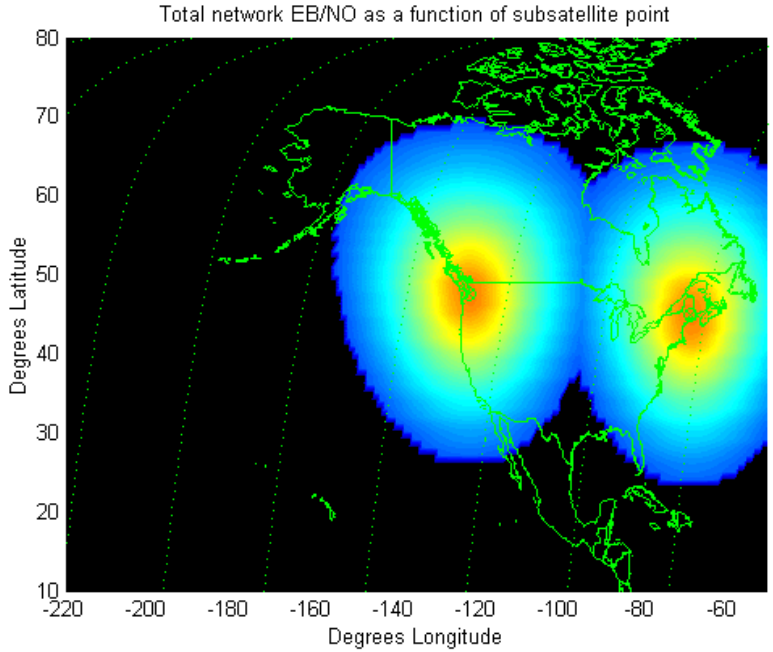
50 Mbps case increases the capacity because the coverage area is more than doubled

Different Rates With Motosat: 7 Dishes Each at Seattle, Bangor

105 Mbps 587gb/day



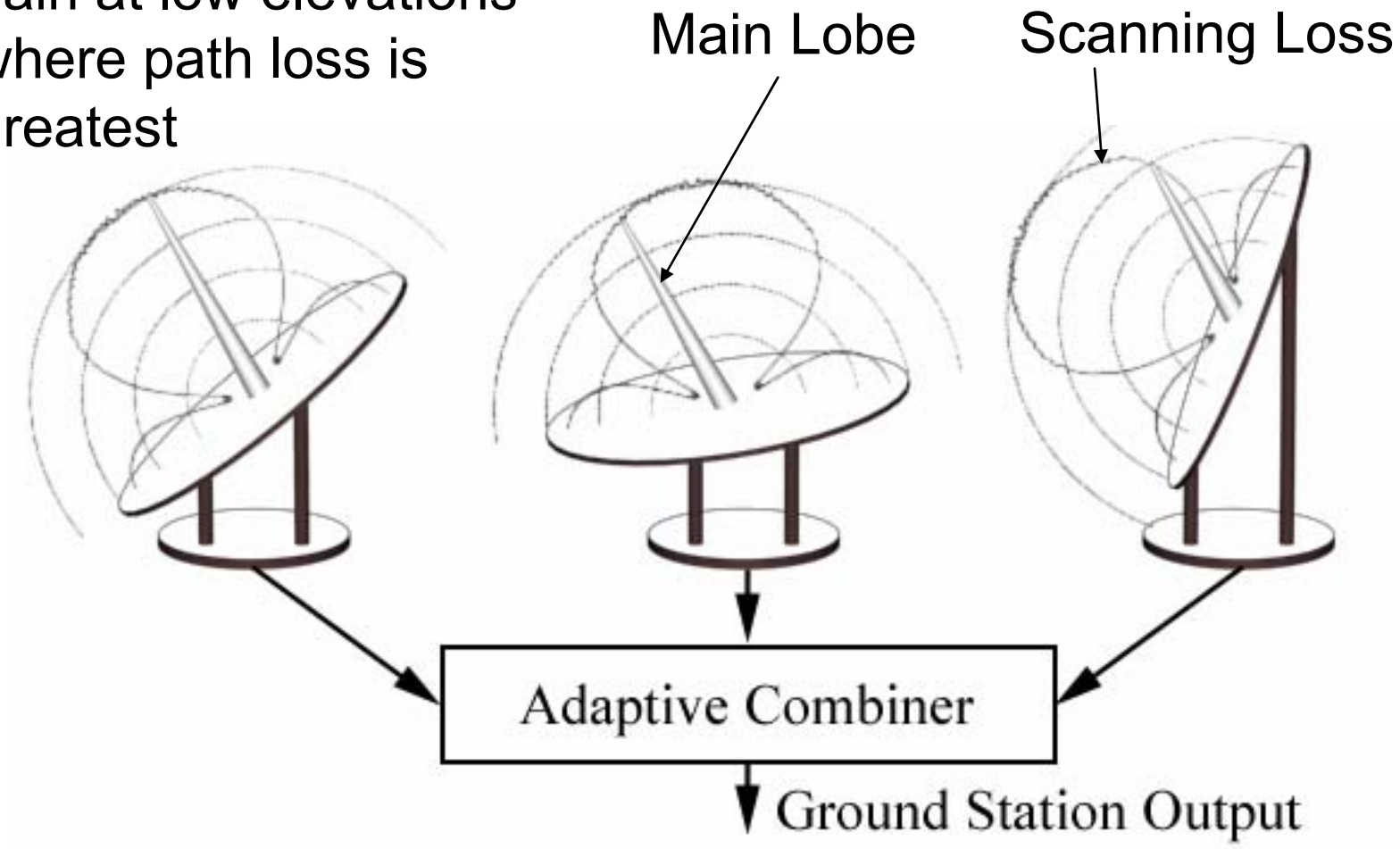
50 Mbps 279gb/day



105 Mbps case already reaches down to 5 degrees elevation, so 50 Mbps does not increase the coverage area

Optimizing the Tilts of SFLs

Tilting puts maximum gain at low elevations where path loss is greatest

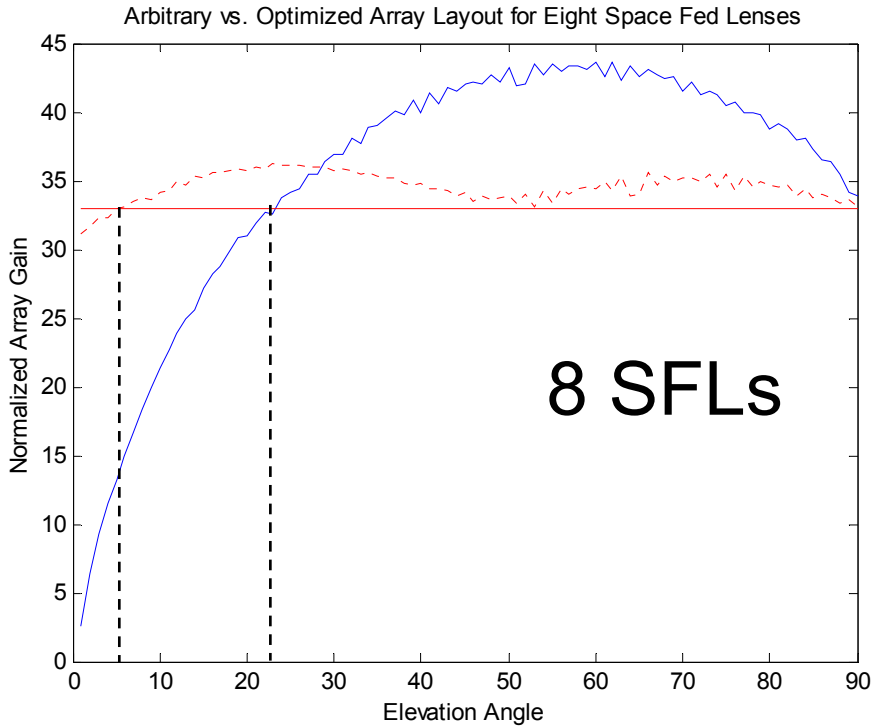


Impact of Tilt Optimization— Link Gain vs. Elevation

all tilted to 50 degrees elevation

minimum link gain for acquisition

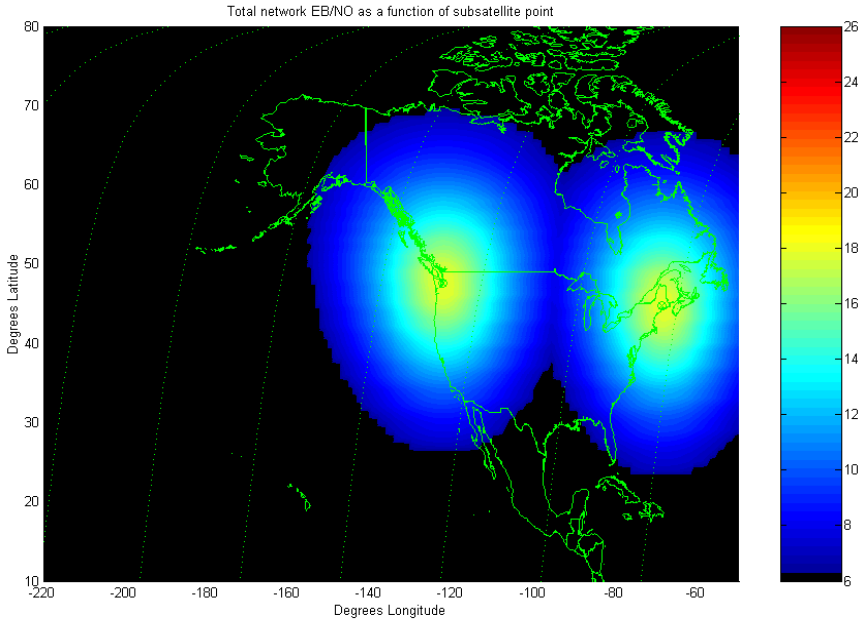
Tilt angles optimized for scan loss



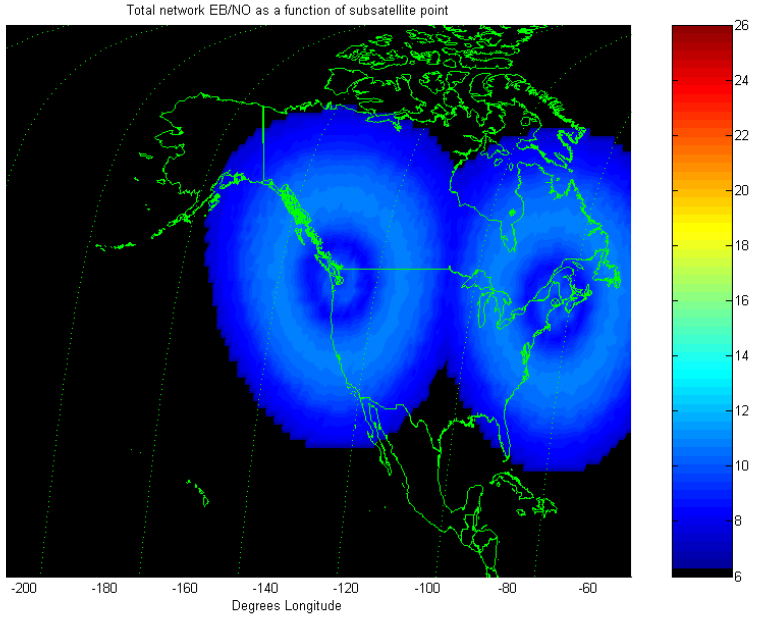
	Lowest Elevation
All tilted to 50^0	***22^0***
Optimized	***5^0***

Small Dishes vs. Optimized SFLs

7-Element Motosat Seattle, Bangor: 105Mbps 587Gb/day

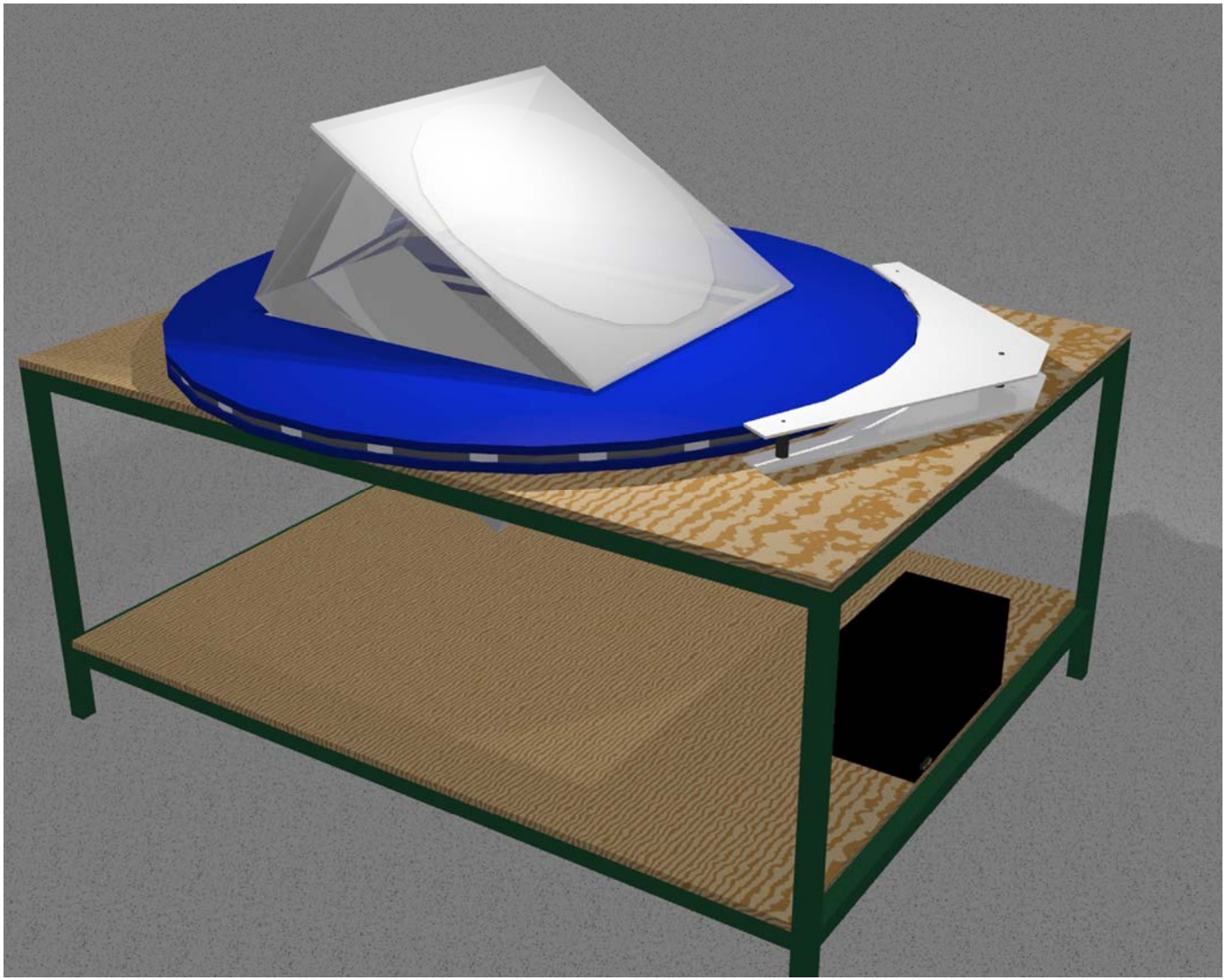


8-Element Optimized SFL Seattle, Bangor: 105Mbps 587Gb/day



No wasted power indicated by nearly uniform blue in the right figure

Prototype SFL Azimuth Turntable Allows Tilt Optimization



Overview

- *Current Technology and Vision*
- *Antenna Technologies*
  - *Inflatable Array*
  - *Space-fed lens*
  - *Reflectarray*
- *Network Capacity Analysis*
- *Conclusion*

Conclusions

- *A few ground stations in non-arctic zones with 7 to 8 directional elements each can equal the download capacity of the 11m dish for EO-1*
- *Lower data rates can still provide large download capability, because they increase the coverage area (connect time)*
- *Optimization of tilts of space fed lenses makes a significant difference*
- *The SFL has the added benefit of multi-satellite tracking capability*